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EARLY BRONZE JERICHO: HIGH-PRECISION ^{14}C DATES OF SHORT-LIVED PALAEOBOTANIC REMAINS

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ABSTRACT. Reliable series of high-precision radiocarbon dates in a stratified archaeological context are of great importance for interdisciplinary chronological and historical studies. The Early Bronze Age in the Near East is characterized by the beginning of the great civilizations in Egypt and Mesopotamia, as well as by urbanization in the Levant. We present stratified high-precision dates of short-lived material of Tell es-Sultan (Jericho), covering Late Proto-Urban/EB I, EB II and EB III layers from Trench III. Our calibrated dates, refined by Bayesian sequence analysis involving Gibbs sampling, are *ca.* 150–300 yr older than conventional archaeological age assessments. The corpus of ^{14}C dates measured in the first decades after the discovery of ^{14}C dating should not be taken too seriously. The ^{14}C dates of Jericho measured by the British Museum ^{14}C laboratory in 1971 appear to be erroneous.

INTRODUCTION

In our continuing research to establish high-precision radiocarbon chronologies of selected sites in the Eastern Mediterranean region, as a chronological basis for interdisciplinary research of human and environmental history (Bruins and Mook 1989; Bruins 1994; Bruins and van der Plicht 1995, 1996), we report the dating results of short-lived organic material from stratified Early Bronze layers at Tell es-Sultan (Jericho). The samples are derived from the excavations conducted by the late Dame Kathleen Kenyon in the period 1952–1958.

An earlier series of ^{14}C dates on charcoal from Early Bronze layers in Trench III, measured in 1971–1972 by the British Museum ^{14}C laboratory (Burleigh 1981), did not show a clear differentiation according to stratigraphy. A later series was unfortunately influenced by an error that affected dates of the British Museum ^{14}C laboratory between 1980 and 1984. One Early Bronze date was measured again later, while the other dates were revised (Bowman *et al.* 1990).

An evaluation of ^{14}C dates of the Early Bronze Age in the region was published in 1977 by Callaway and Weinstein. From a corpus of 55 ^{14}C dates, 25 were rejected, while limitations of some other dates were noted. Nevertheless, they conclude that the ^{14}C dates do not favor the low chronology adopted by Albright and many other archaeologists for the end of EB I (Proto-Urban in Kenyon's classification system) and the beginning of EB II (EB I in Kenyon's classification system). Callaway and Weinstein (1977) pointed out: "In the absence of many more radiocarbon dates and better scientific knowledge about short-term C^{14} fluctuations, the radiocarbon data cannot indicate whether a high date of *ca.* 3050/3000 B.C. or a moderate date of *ca.* 2950 B.C. will ultimately be adopted for the end of EB IC."

Our results of high-precision dates, coupled with much more advanced knowledge about ^{14}C fluctuations, computerized calibration and Bayesian analysis, do answer the above question, at least for

Jericho: The EB I–EB II transition from proto-urban development to the beginning of urbanization is *older* than 3050 BC, as will be presented in detail in the following sections.

METHODS

The samples were analyzed at the conventional ^{14}C laboratory and the accelerator mass spectrometer (AMS) of the Centre for Isotope Research at the University of Groningen. All samples were treated by the acid/alkali/acid (AAA) method. The larger samples of cereal grains were subsequently combusted to CO_2 and purified (Mook and Waterbolk 1985). They were counted for 3 to 4 days to obtain the best possible precision. Enough material was usually available to use the large (25-L) gas counter. The small-sized samples were dated by AMS. We also report the $\delta^{13}\text{C}$ values used for fractionation correction.

RESULTS

Our ^{14}C dating results are based on short-lived organic samples from stratified layers in Trench III. Significant amounts of charred cereal grains constituted ideal material for high-precision ^{14}C dating. Charred seeds of weeds and onion bulbs, though available only in small quantities, also provided important short-lived material for dating additional Early Bronze Age layers in Trench III. The organic matter had been investigated palaeobotanically by Hopf (1983). Information about the stratigraphic context of the samples, their palaeobotany and our new ^{14}C dates is presented in Table 1.

TABLE 1. Sample Data and Results in Stratigraphic Sequence

Lab code	^{14}C age (yr BP)	$\delta^{13}\text{C}$ (‰)	Material*	Sample no.	Stratigraphy Trench III†
GrN-18545	4530 ± 19	–22.24	Charred grains, unsorted, mostly wheat	Jp.N.5.112	XV. I (silo)
GrN-18546	4512 ± 15	–23.15	Charred grains, fragmented cereal	Jp.N.5.112	XV. I (silo)
GrN-18540	4560 ± 16	–23.05	Charred grains, Triticum spec.	Jp.N.5.61	XVI.lxa (silo)
GrN-18541	4465 ± 30	–22.95	Charred grains, Triticum dicoccum	Jp.N.5.61	XVI.lxa (silo)
GrA-222	4360 ± 40	–23.64	Charred seeds of weeds	Jp.N.5.53 Sa-739	XVI.lxii-lxiii
GrA-223 replica 1	4560 ± 30	–24.23	Charred seeds of weeds	Jp.N.5.53 Sa-739	XVI.lxii-lxiii
GrA-6315 replica 2	4330 ± 50	–22.58	Charred seeds of weeds	Jp.N.5.53 Sa-739	XVI.lxii-lxiii
GrA-6332 replica 3	4360 ± 60	–22.58	Charred seeds of weeds	Jp.N.5.53 Sa-739	XVI.lxii-lxiii
GrA-224	4210 ± 40	–24.72	Charred onion bulbs, Allium spec.	Jp.N.5.30 Sa-704	XVII.lxviii-lxixa
GrA-225	4440 ± 40	–25.06	Charred onion bulbs, Allium spec.	Jp.N.5.30 Sa-704	XVII.lxviii-lxixa

*Hopf (1983), personal communication (1990)

†Kenyon (1981)

The gas counter dates of two different grain samples from stage XV phase I (silo), GrN-18545 and GrN-18546 yielded very similar results. The next two grain samples, from stage XVI phase Ixa (silo), also measured by gas counters, yielded dates that are farther apart. The results are, neverthe-

less, acceptable in terms of Bayesian sequence analysis (see Table 2), as GrN-18540 received an agreement of 82.2% in the Gibbs sampling method, which is well above the generally required minimum of 60% (Bronk Ramsey 1995).

Small-sized samples were dated with the new Groningen AMS facility (van der Plicht *et al.* 1995), operational since the summer of 1994. Additional AMS measurements from the same organic sample were made in some cases to check reproducibility of the result. Thus GrA-222 and GrA-223 were prepared from a sample of charred weed seeds of stage XVI, phase lxii-lxiii. The difference of 200 ^{14}C yr (4360 ± 40 and 4560 ± 30) between the two measurements raises the following question: Are both dates from the same short-lived sample of equal quality or has some kind of unknown error occurred in the measuring procedure affecting one or both of the results? Waterbolk (1990:148) states: "If a sample has been measured twice, be it by the same or by an other laboratory, and the results are not congruent, we cannot know which date to reject." However, in this case sufficient sample material was available to make two additional measurements of the short-lived sample in order to try to resolve the above question. These results, GrA-6315 and GrA-6332, produced very similar dating results, *i.e.*, 4330 ± 50 and 4360 ± 60 , virtually the same as GrA-222 (4360 ± 40). On the basis of these results, we now know that GrA-223 should be rejected, being erroneous in comparison with the three other dates of the same sample. The average date was taken of GrA-222, GrA-6315 and GrA-6332 for calibration and Bayesian analysis with Gibbs sampling (see Table 2).

Two duplicate AMS measurements were made from another small-sized sample of short-lived material, composed of charred onion bulbs (stage XVII, phase lxviii-lxix). The age difference between the two duplicate measurements of the same sample, GrA-224 (4210 ± 40) and GrA-225 (4440 ± 40), is 230 ^{14}C yr. Additional measurements could not be made in this case to check these results. Therefore, no date is rejected, according to the criterion of Waterbolk (1990:148), although the younger date GrA-224 (4210 ± 40) seems to fit better with the stratigraphic sequence and calibration curve.

The dates, measured by both gas counters and AMS, are in good agreement with their archaeological stratigraphic sequence. The calibrated dates are presented with the standard 1- σ confidence levels; the 2- σ dates appeared to be hardly different in the studied samples. The ^{14}C dates were calibrated in three different ways (see Table 2):

1. (Column 2) For short-lived samples, a calibration curve based on more individual tree ring data is generally advocated. Thus, the decadal calibration curve by Stuiver and Becker (1993) was chosen as it covers the entire period of the reported samples. The calculations were carried out with the Groningen Radiocarbon Calibration Program (CAL20 version, Jan. 1995) (van der Plicht 1993). No smoothing factor was used ($S=0$). Hence, all the detailed wiggles in the calibration curve are taken into account in the calibrated date. There are indeed many wiggles in this part of the calibration curve, which resulted, in the worst case, in 10 possible calibrated age ranges for sample GrN-18546 (4512 ± 15 BP), notwithstanding its very small standard deviation. The calibrated dates in historical years are in all cases less precise than the original BP dates in ^{14}C years, but the results are, nevertheless, very valuable.
2. (Column 3) Calibration was also carried out with the less-detailed bidecadal calibration curve of Stuiver and Pearson (1993) and Pearson and Stuiver (1993), using the OxCal program (Bronk Ramsey 1995). The results are less detailed than in column 2, due to the bidecadal calibration curve and smoothing built into the OxCal program.
3. (Column 4) The OxCal program has the important option to include relative age information in the calibration calculation for a sequence of samples with stratigraphic relationships, through

TABLE 2. Calibrated Dates (1- σ Confidence Level)

Lab code., date (yr BP)	Calibrated date (cal BC)*	Calibrated date (cal BC)†	Sequence calib. through Bayesian analysis– Gibbs sampling (cal BC)‡	Trench III stratigraphy§	Archaeological age (BC)#
GrN-18545 4530 \pm 19	3340–3332 3320–3309 3220–3189 3186–3171 3155–3151 3140–3121 3111–3103	3340–3300 (0.25) 3230–3180 (0.38) 3160–3110 (0.36)	3350–3290 (0.59) 3240–3190 (0.41) Agreement 97.5%	XV. I (silo) PU/EB-I	ca. 3050
GrN-18546 4512 \pm 15	3334–3328 3324–3318 3312–3306 3279–3264 3232–3213 3194–3182 3173–3168 3159–3154 3124–3108 3105–3101	3340–3260 (0.34) 3240–3220 (0.12) 3200–3100 (0.54)	3340–3260 (0.74) 3240–3210 (0.19) 3190–3170 (0.07) Agreement 97.9%	XV. I (silo) PU/EB-I	ca. 3050
GrN-18540 4560 \pm 16	3352–3337 3208–3200 3177–3175 3152–3138	3360–3330 (0.41) 3220–3190 (0.28) 3160–3130 (0.31)	3210–3195 (0.14) 3160–3115 (0.86) Agreement 82.4%	XVI.lxa (silo) EB-II	3050–2700
GrN-18541 4465 \pm 30	3328–3323 3306–3278 3264–3231 3168–3158 3116–3115 3101–3080 3069–3044	3300–3230 (0.47) 3180–3160 (0.08) 3110–3030 (0.45)	3180–3160 (0.11) 3120–3030 (0.89) Agreement 104.6%	XVI.lxa (silo) EB-II	3050–2700
GrA-222, -6315, -6332 4350 \pm 27	3010–2982 2965–2953 2925–2906 2905–2902	3030–2980 (0.69) 2930–2910 (0.31)	3024–2987 (1.00) Agreement 99.5%	XVI.lxii-lxiii EB-II	3050–2700
GrA-224 4210 \pm 40	2886–2847 2811–2784 2781–2756 2741–2732 2722–2705 2647–2642	2890–2860 (0.18) 2810–2690 (0.82)	2890–2860 (0.18) 2810–2690 (0.82) Agreement 100.0%	XVII.lxviii-lxixa EB-III	2700–2300
GrA-225 4440 \pm 40	3301–3284 3260–3234 3166–3161 3100–3028 3022–3013 2980–2967 2951–2932	3300–3240 (0.17) 3110–3020 (0.53) 2990–2920 (0.30)	2974–2927 (1.00) Agreement 97.1%	XVII.lxviii-lxixa EB-III	2700–2300

*Decadal calibration curve Stuiver and Becker (1993) with method of van der Plicht (1993) (CAL20 version Jan. 1995) (S=0, no smoothing)

†Bidecadal calibration curve Stuiver and Pearson (1993), Pearson and Stuiver (1993) with method of Bronk Ramsey (1995) (OxCal v.2.18)

‡As in column 3, but incorporating the stratigraphic relationships between the samples in the calibration: Bayesian analysis with Gibbs sampling (Bronk Ramsey 1995), resulting in an overall agreement of 91.7%

§Archaeological stratigraphy: Stage, phase and cultural classification (Kenyon and Holland 1983)

#Example of archaeological age assessment (Mazar 1990)

Bayesian analysis involving Gibbs sampling (Bronk Ramsey 1995). The sequence of the investigated samples was fed into the program from old to young: first GrN-18545 and GrN-18546 both belonging to the same phase, followed by GrN-18540 and GrN-18541 in a younger stratigraphic phase; then the average BP date of GrA-222, GrA-6315 and GrA-6332, and finally the youngest stratigraphic phase, represented by samples GrA-224 and GrA-225. The program calculated the best match for each sample with the calibration curve, in relation to their stratigraphic position in the sequence, through a mathematical procedure called Gibbs sampling (Bronk Ramsey 1995). The program also verifies the degree of agreement between the dates, their sequence and the calibration curve, which is very good indeed in our case, 97.5%, 97.9%, 82.4%, 104.6%, 99.5%, 100.0% and 97.1%, respectively, for the individual dates and an overall agreement of 91.7%. These Bayesian calibration results (Table 2, column 4), therefore, are most important and more precise, with narrower age ranges.

DISCUSSION

Comparison with BM Dates of Trench III, Measured in the 1970s and 1980s

A comparison of the new high-precision dates with an older series of charcoal dates, measured in the early 1970s in the British Museum ^{14}C laboratory (Burleigh 1981), shows large differences. All the ^{14}C dates of Jericho Trench III are presented in stratigraphic order in Table 3. Most of the BM dates from the 1970s are roughly 300 ^{14}C yr younger than our new GrN series, measured in the 1990s on short-lived material. Normally, wood charcoal dates are older than dates from short-lived organic material of the same stratigraphic layer, as we clearly demonstrated in a very detailed study regarding the end of the Middle Bronze Age at Jericho (Bruins and van der Plicht 1995). The conclusion is, therefore, inevitable that most of the BM dates from the 1970s of Trench III are much too young and should be rejected, with the exception of BM-553 and BM-554. One should be aware that the erroneous BM series of Jericho was used to some extent by Kenyon and Holland (1983) in a pottery-related stratigraphic assessment of the tell. A comparative analysis by Waterbolk (1990) of Near-Eastern ^{14}C dates also showed a tendency for BM dates to be on the younger side as compared with other ^{14}C laboratories.

A second series of Jericho samples was measured in the British Museum ^{14}C laboratory in 1981 (Burleigh 1983). It was found that dates issued between 1980 and 1984 were in error. Some samples could be measured again later, serving as a basis for revising the dates where possible. The erroneous dates were on average 200–300 ^{14}C yr too young (Bowman *et al.* 1990). It is noteworthy that we find about the same difference between our Groningen dates and most BM dates from Trench III measured in 1971. Therefore, the conclusion is inevitable that the ^{14}C dates of Jericho measured in the British Museum ^{14}C laboratory and published in Volume Three (Kenyon 1981; Burleigh 1981) and Volume Five (Kenyon and Holland 1983; Burleigh 1983) of *Excavations at Jericho* cannot be trusted and should not be used in archaeological evaluations. The newly measured date (BM-1780N) of the 1981 Jericho Trench III BM series fits stratigraphically very well indeed in our Groningen series, while some of the revised dates (Bowman *et al.* 1990) appear to fit quite well (BM-1779R and BM-1778R), as shown in Table 3.

Waterbolk (1990) published an evaluation of quality differences between ^{14}C laboratories on material from southwest Asia and Egypt. He also reached the conclusion that BM dates tended to be too young. It is, however, fair to mention *vis-à-vis* the British Museum Radiocarbon Laboratory, that dates measured by them later in the 1980s and 1990s should not be judged in the light of the above

TABLE 3. List of All ^{14}C Dates for Jericho Trench III, Arranged in Stratigraphic Order

Trench III	Lab no.	BM-series 1970s (charcoal)	BM-series 1980s (charcoal)	GrN-series 1990s (short-lived)
XIV. xlii	BM-548	4175 \pm 48		
XV. I	GrN-18545			4530 \pm 19
XV. I	GrN-18546			4512 \pm 15
XV. li-lii	BM-549	4204 \pm 49		
XVI. lxa	GrN-18540			4560 \pm 16
XVI. lxa	GrN-18541			4465 \pm 30
XVI. lxi-lxii	BM-550	4126 \pm 50		
XVI. lxii-lxiii	BM-1778R		4300 \pm 120	
XVI. lxii-lxiii	BM-1779R		4390 \pm 130	
XVI. lxii-lxiii	GrA-222			4360 \pm 40
XVI. lxii-lxiii	GrA-6315			4330 \pm 50
XVI. lxii-lxiii	GrA-6332			4360 \pm 60
XVI. lxv-lxvi	BM-551	4080 \pm 42		
XVII. lxviii	BM-552	4115 \pm 39		
XVII. lxviii	BM-1780N		4320 \pm 50	
XVII. lxviii-lxixa	GrA-224			4210 \pm 40
XVII. lxviii-lxixa	GrA-225			4440 \pm 40
XVIII. lxxii	BM-553	3922 \pm 78		
XIX. lxxvi	BM-554	4170 \pm 42		
XIX. lxxvi-lxxviii	BM-1781R		4350 \pm 110	

conclusions, as noted by Waterbolk (1990): "In the BM case we have good reasons to expect that at the moment high quality dates are produced."

Comparison with Archaeological Age Assessments

GrN-18545 and GrN-18546 are from a silo built during stage XV, phase I, when there was a very complete rebuilding, although the plan of the buildings remained essentially the same as before. The buildings and grain contents of the silo of phase I were subsequently destroyed by a fierce fire in phase li-lii (Kenyon 1981). Stage XV is represented by the largest number (27) of phases in Trench III, being assigned to a transitional period between the end of the Proto-Urban and the end of Kenyon's EB I. The vessels from phase li-lii include the spouted jar ("teapot") and specific bowls which indicate that the pottery assemblage comes late in the Jericho Proto-Urban period (Kenyon and Holland 1983). The transition from Proto-Urban to EB I, often classified in other systems as EB I to EB II, is given a high date of *ca.* 3050/3000 BC, or a moderate date of *ca.* 2950 BC by Callaway and Weinstein (1977), partly based on ^{14}C dates from the 1970s and before, including the erroneous BM dates from Jericho. This transition is dated on archaeological considerations to *ca.* 3050 BC by Mazar (1990) and to *ca.* 2950/2900 BC by Ben-Tor (1992). Our high-precision ^{14}C dates on short-lived material give calibrated dates that are substantially older than all of the above quoted dates. The calibrated ages seem accurate but wide in range due to the shape of the calibration curve in this time trajectory. Refined calibration through Bayesian analysis with Gibbs sampling of GrN-18545 and GrN-18546 gives an age range of 3350–3170 cal BC for this stratigraphic phase, which is 120–400 yr older than the above archaeological age assessments (see Table 2, column 4 for more detailed information of this date).

GrN-18540 and GrN-18541 are from a silo belonging to stage XVI, phase Ixa. The transition in Kenyon's system from EB I to EB II has taken place by stage XVI (Kenyon and Holland 1983). The duration of Kenyon's EB I and EB II periods combined (EB II in other classification systems) is put at *ca.* 3050–2700 BC by Mazar (1990). The youngest of the above ^{14}C dates, GrN-18541, fits the stratigraphy and calibration curve best. Its calibrated date has a range of 3328–3044 cal BC according to the decadal calibration curve of Stuiver and Becker (1993), calculated with the Groningen Radiocarbon Calibration Program (van der Plicht (1993); $S=0$, no smoothing). Sequence calibration through Bayesian analysis with Gibbs sampling, using the OxCal Program (Bronk Ramsey 1995) and the bidecadal calibration curve of Stuiver and Pearson (1993) and Pearson and Stuiver (1993) gives a calibrated age range, both dates put together, of 3210–3030 cal BC. These results are again considerably older than the archaeological age assessment (Table 2).

The end of Kenyon's EB II is probably represented by phase Ixii-Ixiii (Kenyon and Holland 1983), dated by three similar AMS results (GrA-222, GrA-6315, GrA-6332) with an average date of 4350 \pm 27 BP. Sequence calibration with Bayesian analysis gave a narrow range of 3024–2987 cal BC in historical years (Table 2). The end of EB II is *ca.* 2700 BC according to Mazar (1990). Our calibrated date, based on the average of three similar AMS dates, is 280–320 yr older than the archaeological age assessment.

The youngest stratigraphic Early Bronze phase in our Jericho series (GrA-224 & GrA-225) belongs to stage XVII, characterized by fully developed EB III pottery forms (Kenyon and Holland 1983). The youngest ^{14}C date (GrA-224) fits best with the stratigraphy and calibration curve. Sequence calibration with Bayesian analysis of GrA-224 gives an age range of 2890–2690 cal BC (Table 2), which is again considerably older than the archaeological age assessment for the EB III period, according to Mazar (1990): 2700–2300 BC.

CONCLUSION

High-precision ^{14}C dating of a stratified series of short-lived organic samples from Early Bronze Jericho (Trench III), subsequently analyzed by sequence calibration through Bayesian analysis involving Gibbs sampling, clearly show considerably older dates than those based on archaeological age assessments. The age difference is roughly in the order of 150 to 300 yr. The Egyptian calendar and archaeological synchronisms form the basic pillars of the archaeological dates. A more thorough archaeological evaluation of our dates in relation to Egypt and the archaeological dating framework will be published elsewhere.

Most ^{14}C dates from Early Bronze Jericho (Trench III), measured in 1971 by the British Museum ^{14}C laboratory are generally 200–300 yr too young, as compared to our new dates on short-lived material. A similar age discrepancy had already been noted for BM dates issued in the period 1980–1984. Our findings raise a question mark for the reliability of other BM dates of ancient Jericho measured prior to 1984, and perhaps for the reliability in general of ^{14}C dates measured during the first decades after the discovery of ^{14}C dating by Prof. Libby in the late 1940s.

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